

SWOT Ocean Cal/Val

A model framework for evaluating
in-situ measurement to estimate

synoptic SSH

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OSSE based on ECCO2-Ice (llc4320)

- 1.9km resolution
- 90 levels, 1-2m resolution in the upper 50m
- With tides and internal waves
- Hourly output

OSSE

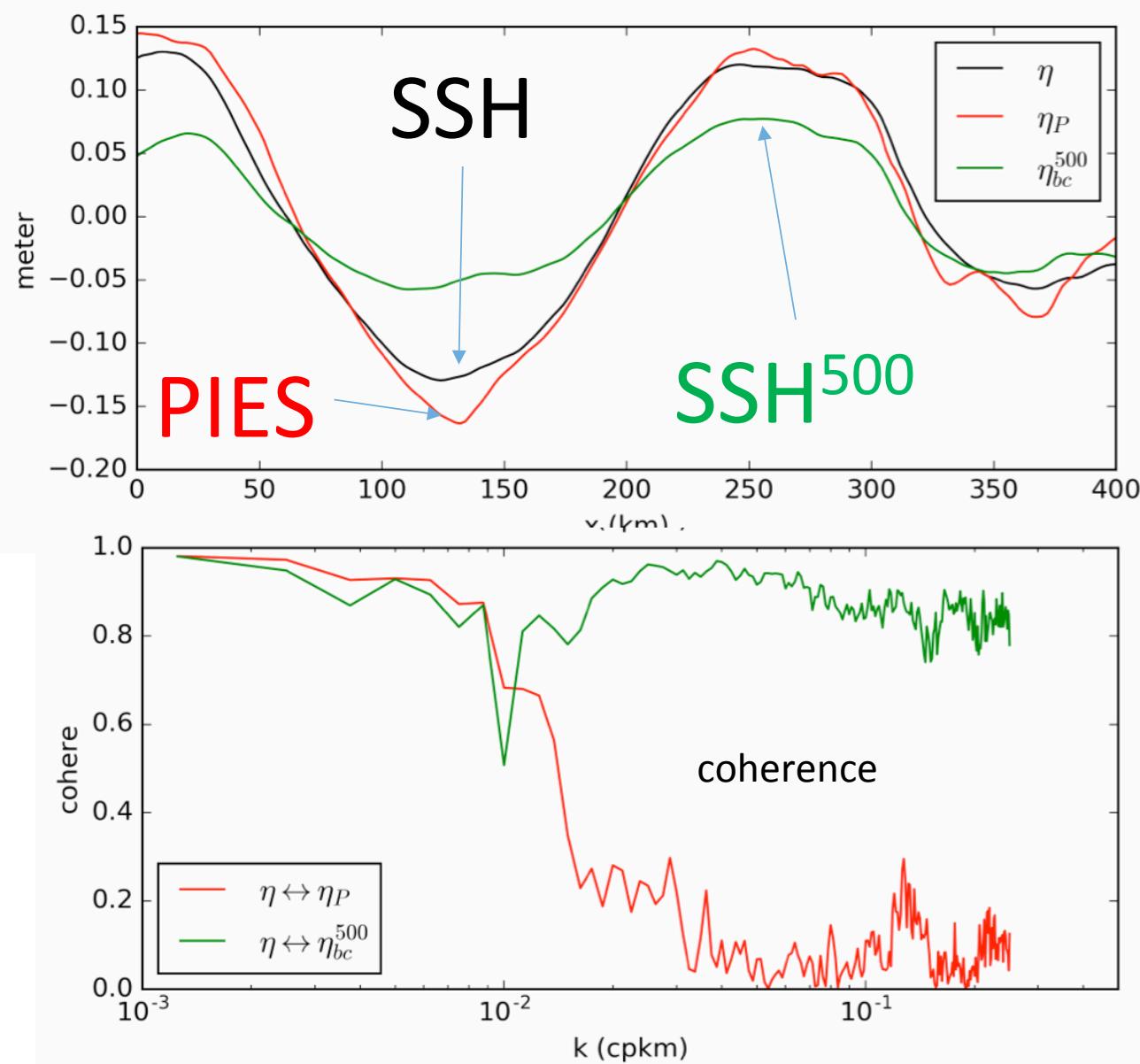
without instrument or measurement noise

- PIES
 - Construct a regional lookup curve between PIES signal and full-depth dynamic height
 - Calculate sound speed based on model T/S
 - Build SSH based on the lookup curve, following Baker-Yeboah et al. 2009.
- UCTD
 - Measurement only depends on depth due to the free-fall feature
 - Consider realistic boat speed
 - T/S on model vertical grid is used to calculate UCTD dynamic height
- Mooring
 - Linearly interpolate the model T/S to the vertical positions of mooring CTD
 - The interpolated T/S is used to calculate mooring dynamic height

At low frequency

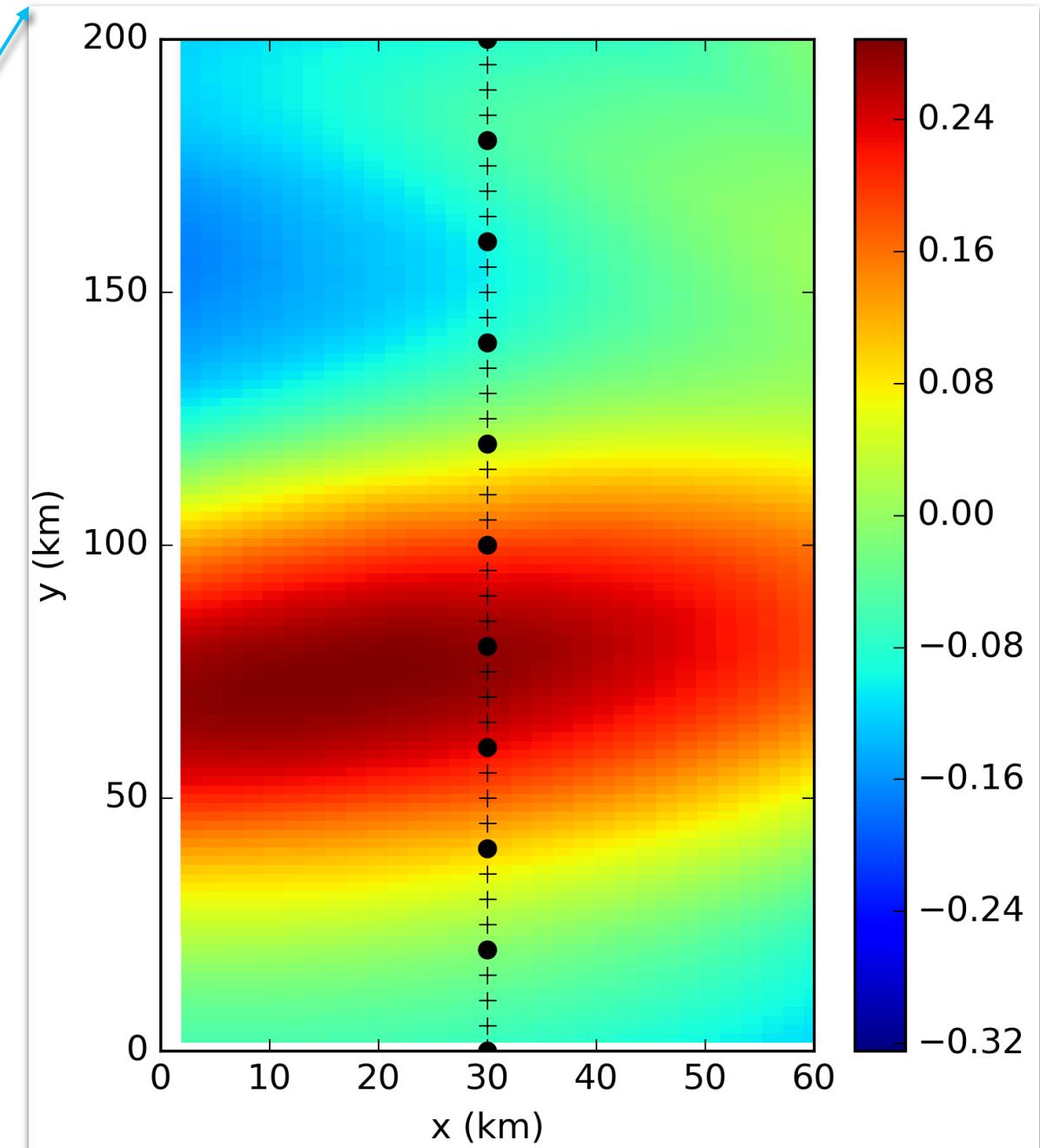
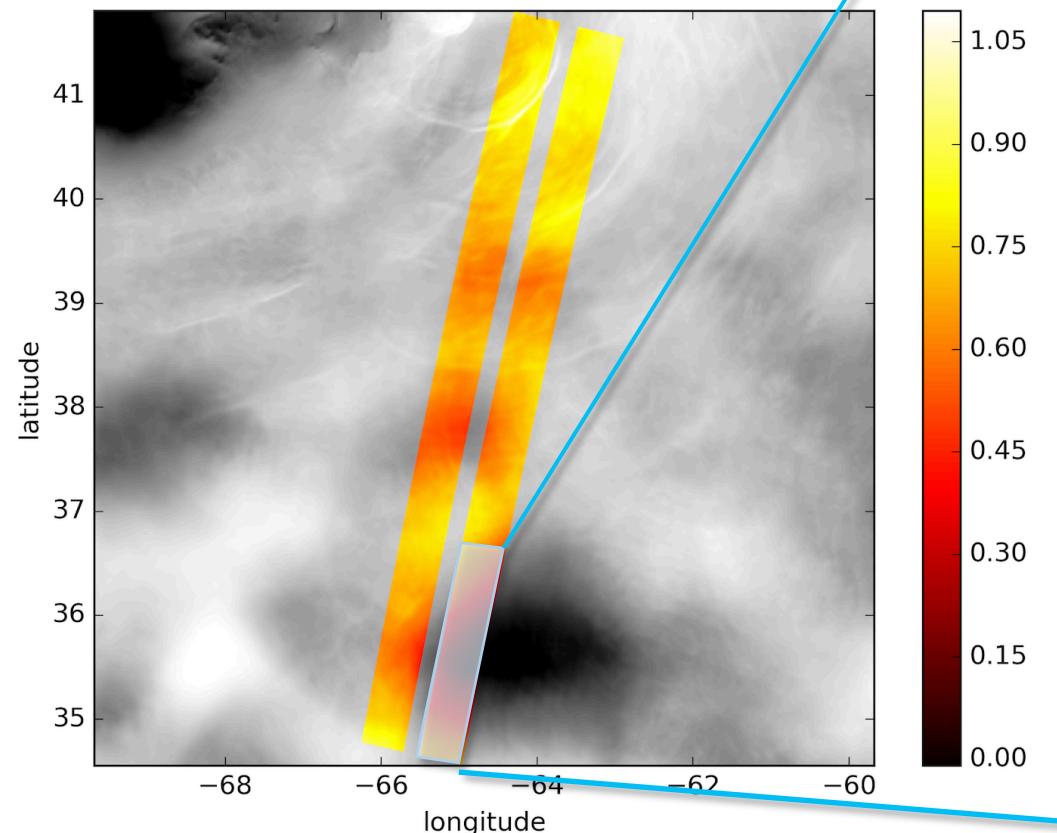
PIES: good for mesoscale
 SSH^{500} : good for submesoscale

- Upper 500 meter T/S misses deep ocean influence, underestimates mesoscale signal.
- The acoustic travel time is insensitive to small-scale changes in thermal structure, PIES signal mostly reflects mesoscale variability.

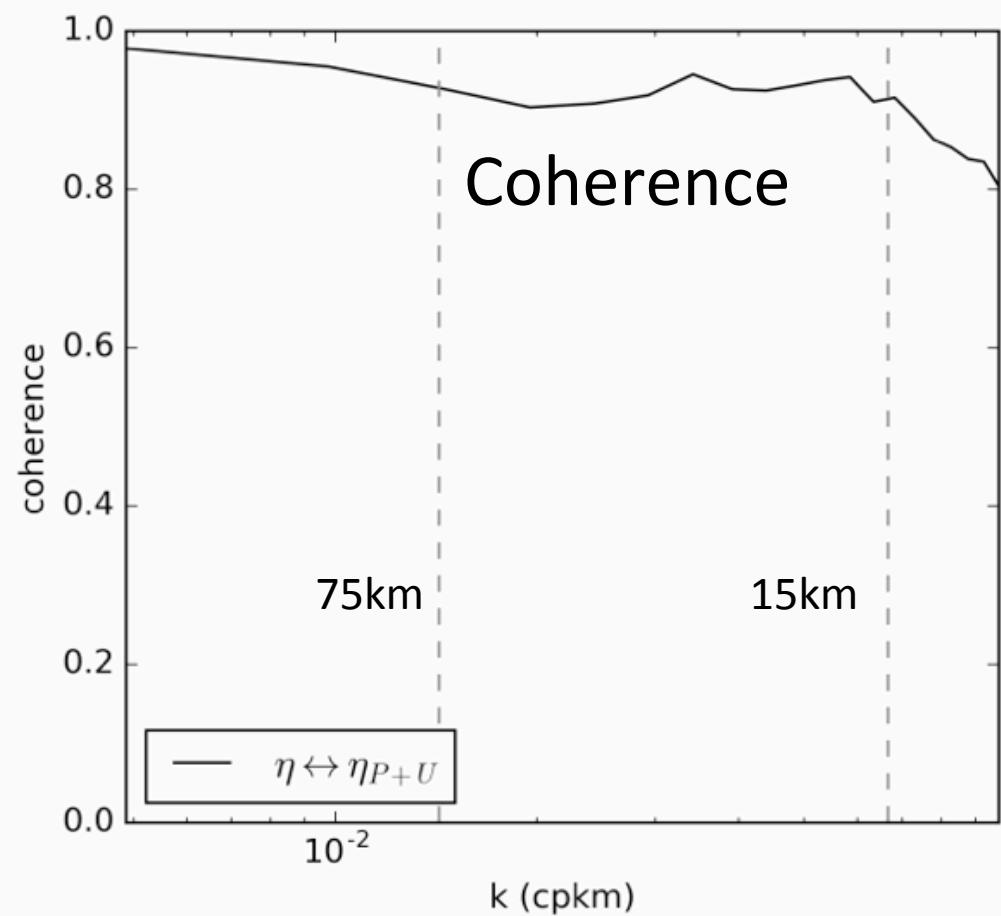
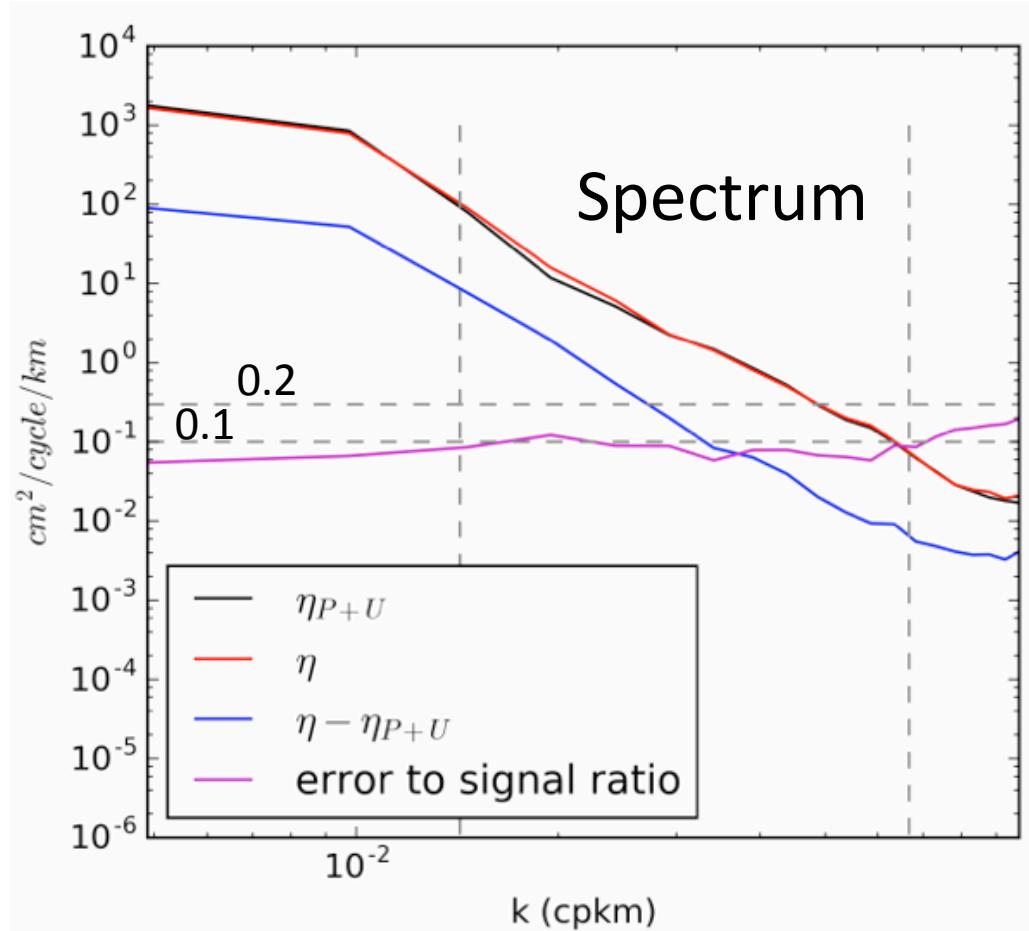


Combine PIES and UCTD

1. 11 PIES covering 200 km (20km distance)
2. UCTD finishes 200 km within 12 hours with measurements 5km apart

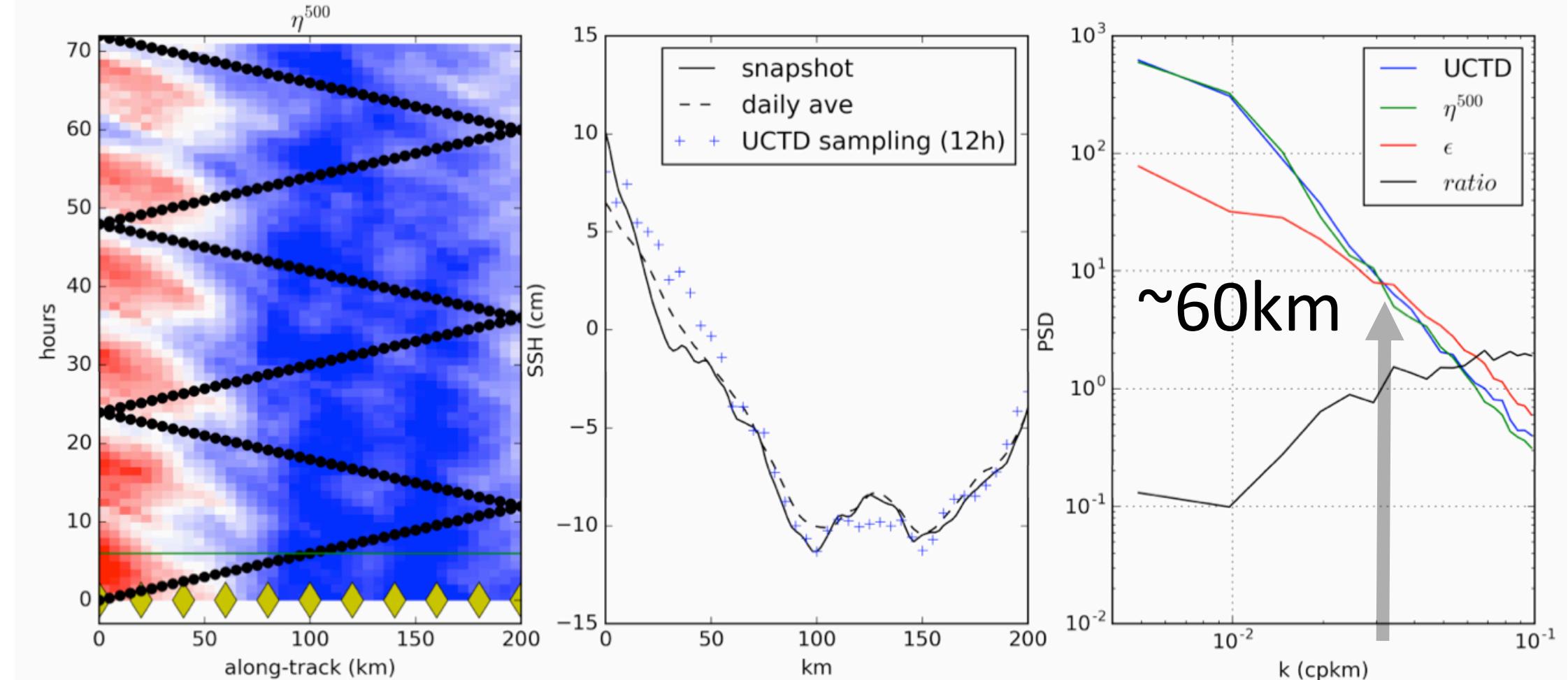


PIES+UCTD measurements of slow motions



1. PIES+UCTD catches low frequency ($>1\text{d}$) motions with $<20\%$ error.
2. It is important to check the spectrum of difference and coherence, because two signals could look very different even with the same spectrum.

Influence of high frequency motions on UTCD measurements



Color: Hovmöller diagram of the dynamic height based on upper 500m TS.

Dots: UTCD sample tracks in (x,t) coordinate.

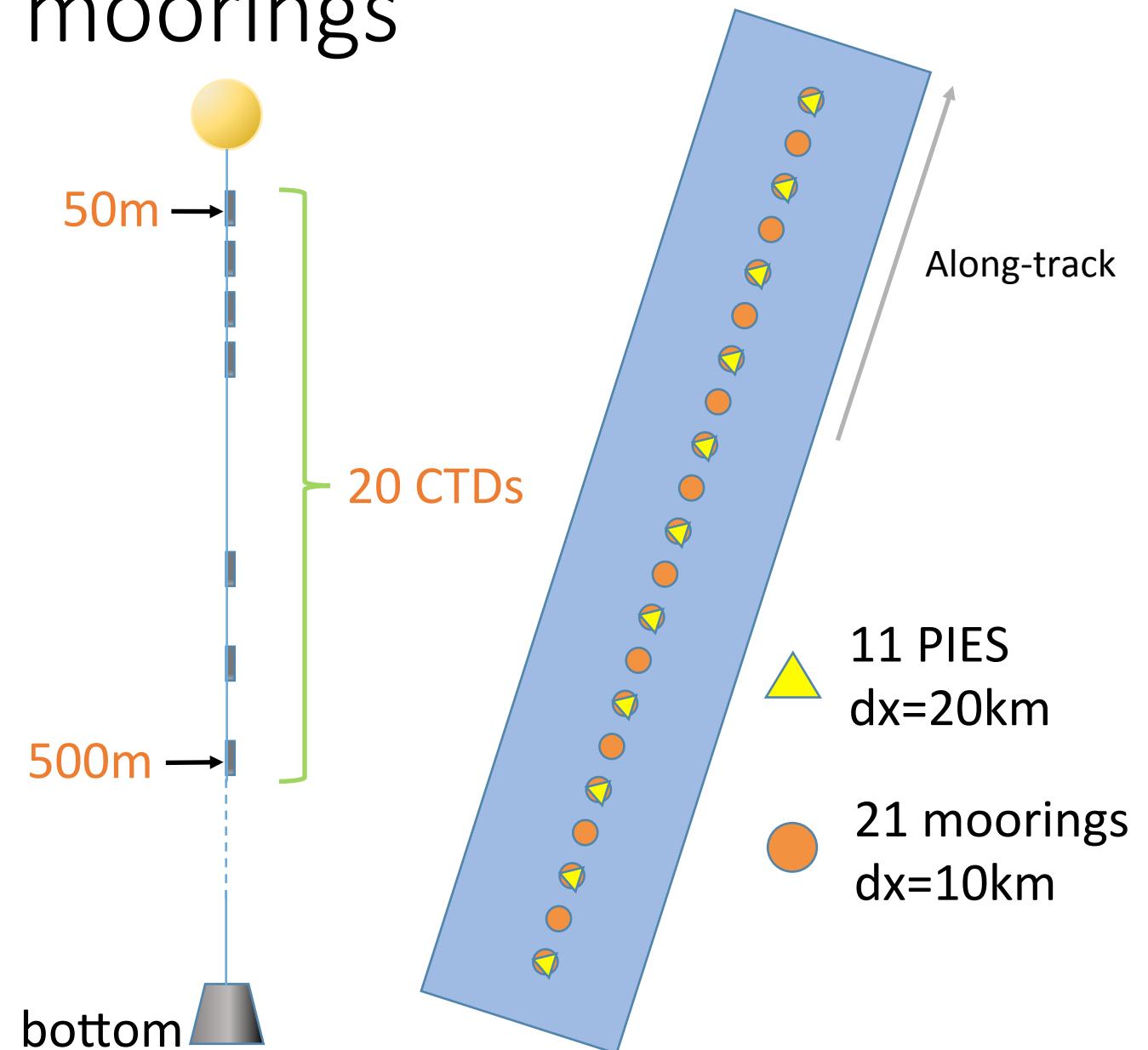
Diamonds: PIES along-track location

Along track surface heights

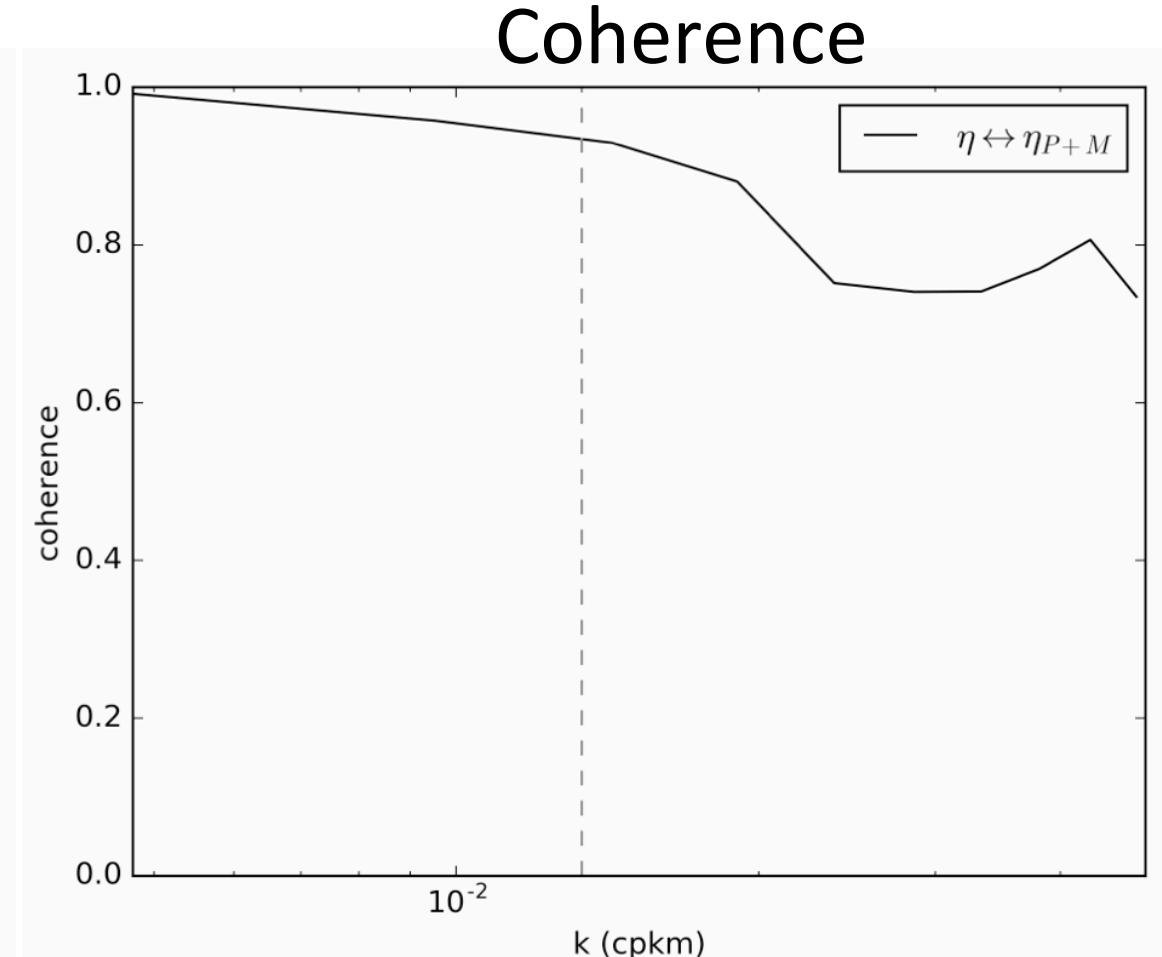
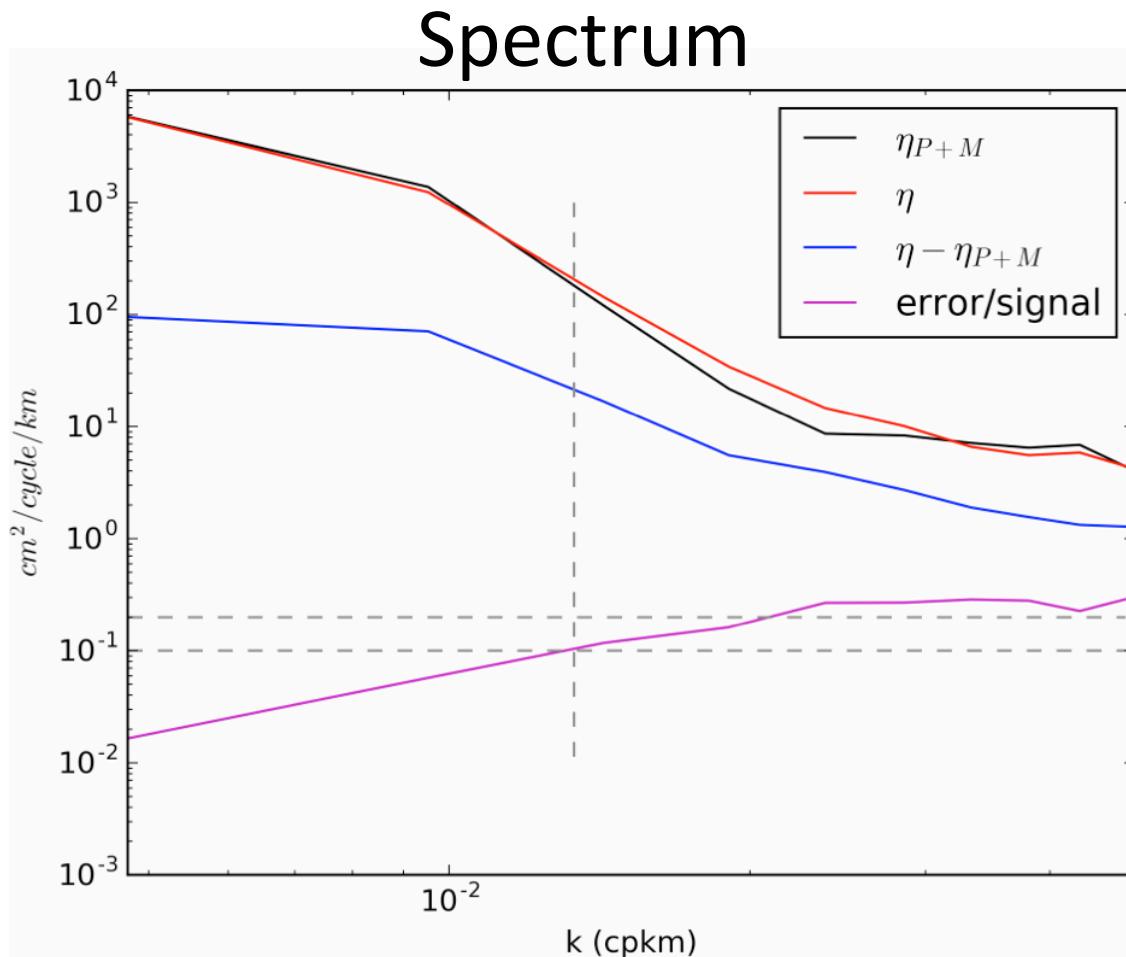
Spectrum and the error-to-signal ratio
Error becomes as large as signal near 60km.

Substitute UCTD with moorings

- First CTD at 50m
- Assume uniform T/S within upper 50m
- 20 CTDs within the upper 500m
- 5m distance near surface
- 50m distance near 500m
- Subsample model T/S using linear interpolation
- dynamic height of upper 500m
- Low-pass PIES, high-pass moorings



Substitute UCTD with moorings



Combining moorings and PIES yields <30% error even **with high frequency motions** considered.

Conclusions

1. PIES
 1. Mesoscale structure
 2. high-frequency barotropic (bottom) signals.
2. UCTD
 1. Good for the submesoscale structure of low frequency signals
 2. but aliased by high frequency internal-wave motions.
3. Mooring
 1. Good for high frequency measurement
 2. Potential logistic complications
4. PIES+UCTD
 1. Good for low frequency signals (<20% error). low cost?
5. PIES+Mooring
 1. <30% error with high frequency signal included.

To-do

1. Test the realism of internal tide/wave simulation.
2. Test the robustness of the results in different regions and time, with different simulations.
3. Explore the benefits of adding Lagrangian measurements such as Argo, Glider and AUVs.
4. Explore UCTD sampling of a smaller domain (50km?).

BACK-UP figures

Conclusions

1. PIES provides a good reference for large spatial scale structure and high-frequency barotropic (bottom) signals.
2. UCTD of upper 500m provides good information in submesoscale for low frequency signals (longer than a day), but aliased by high frequency internal-wave motions.
3. Combining PIES and UCTD yields an SSH reconstruction with <20% error only for low frequency signal. The error-signal ratio exceeds 1 for wavelength below 60km if high frequency motions are included.
4. Combining PIES and moorings yields a reconstruction with <30% error even with high frequency motions considered.



Wikipedia.com

“No man ever steps in the same river twice, for it's not the same river and he's not the same man.”

--Heraclitus

UCTD (Underway CTD)

CTD Profiling from a moving vessel

- Achieve over 400-500m vertical profiles while underway at 10kts
- Fast sampling speed enables high spatial resolution
- High quality freefall CTD data
- Compact and portable for deployment on multiple vessels

<https://youtu.be/P4GO537QVUo>



PIES (Pressure, inverted echo sounder)



- Emits 12kHz sound pulses.
- Measures the round trip travel time of acoustic pulses to sea surface.
- Measures bottom pressure.

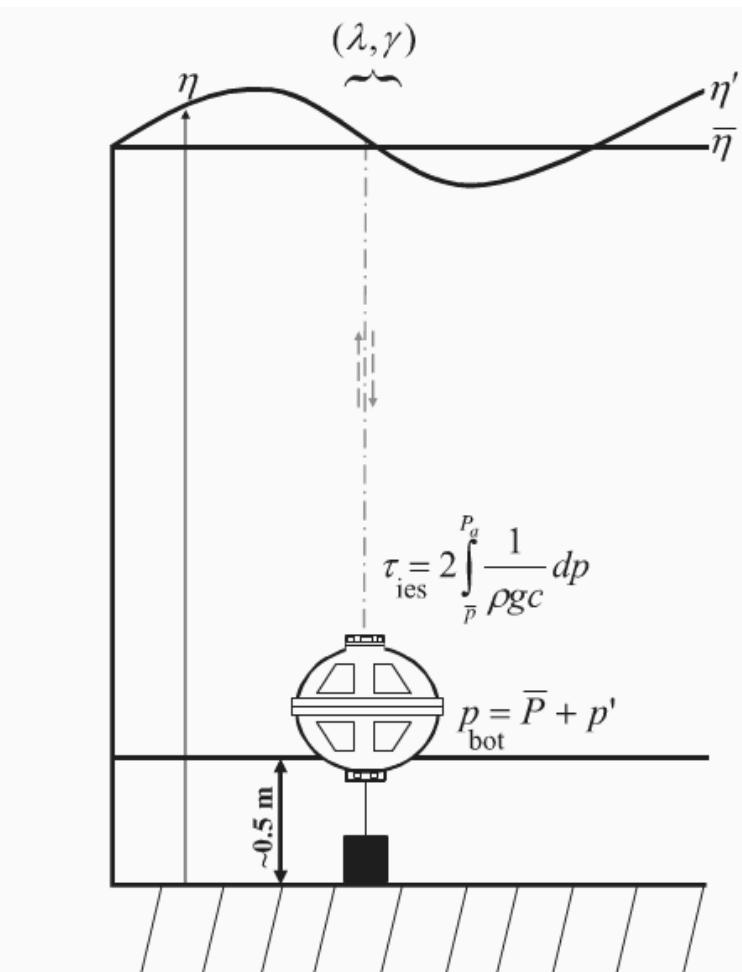
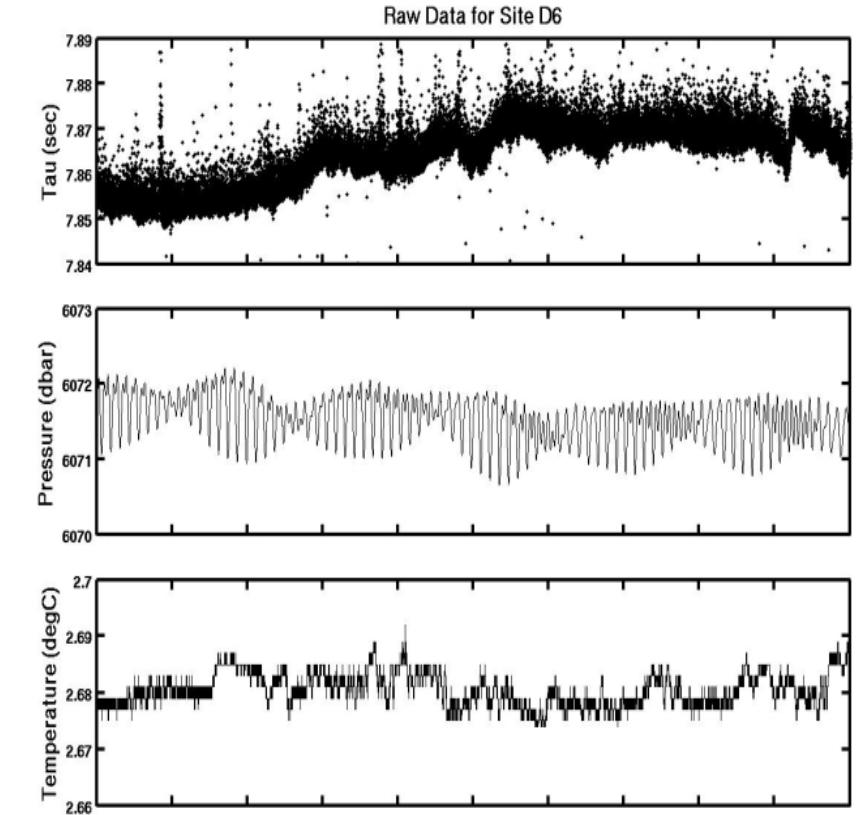


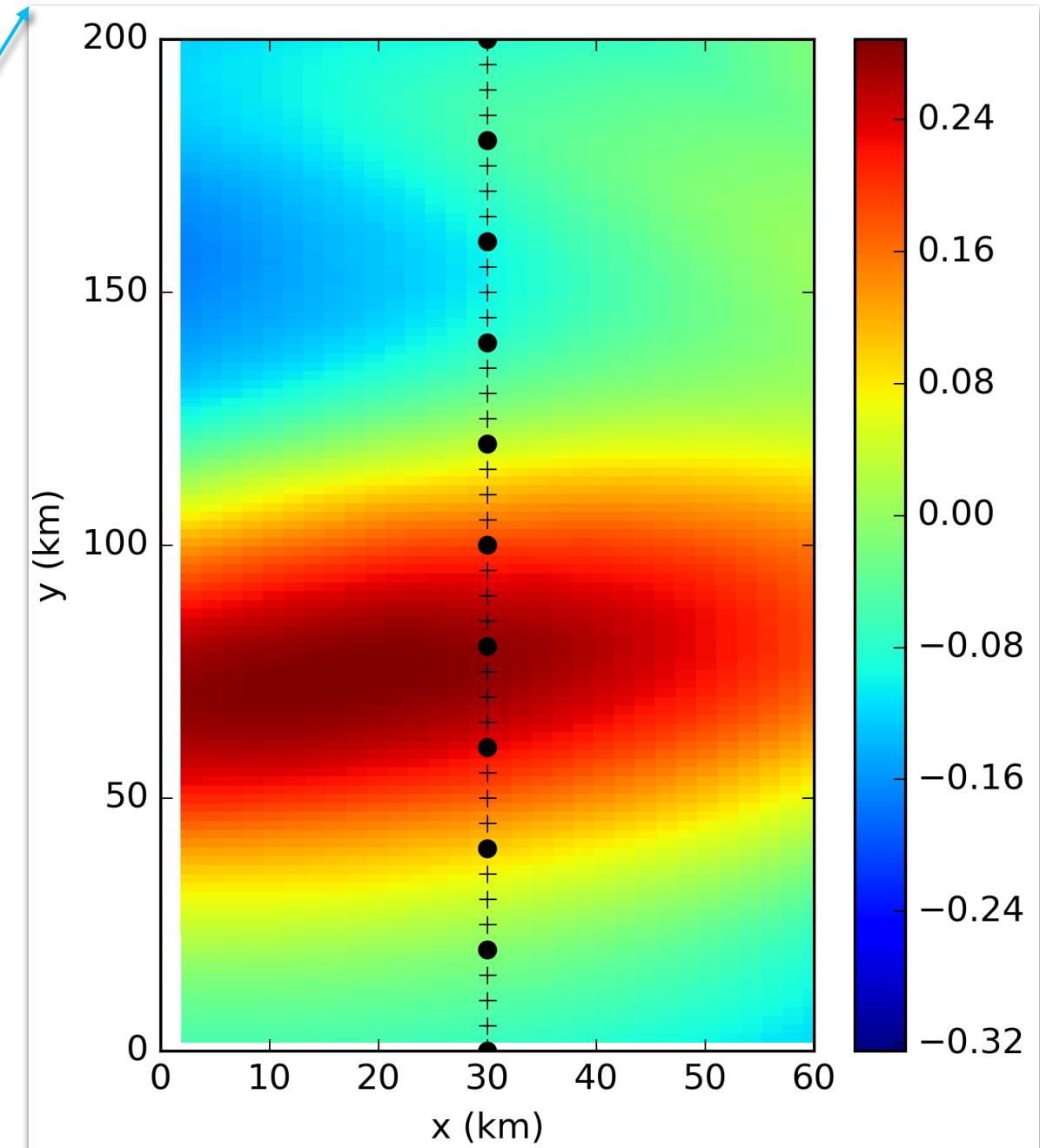
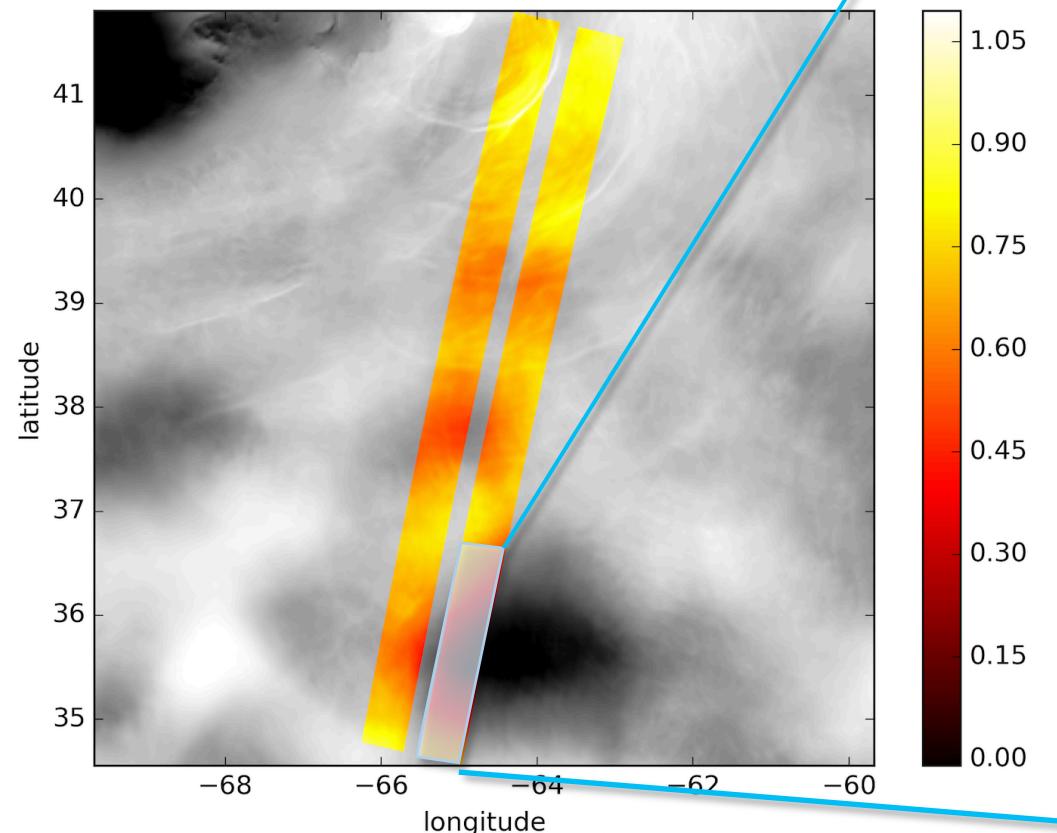
FIG. 2. A PIES instrument moored near the seafloor at latitude λ and longitude γ . Measurements include bottom pressure (p_{bot}) and round-trip acoustic travel time (τ_{ies}).



Baker-Yeboah et al. (2009)

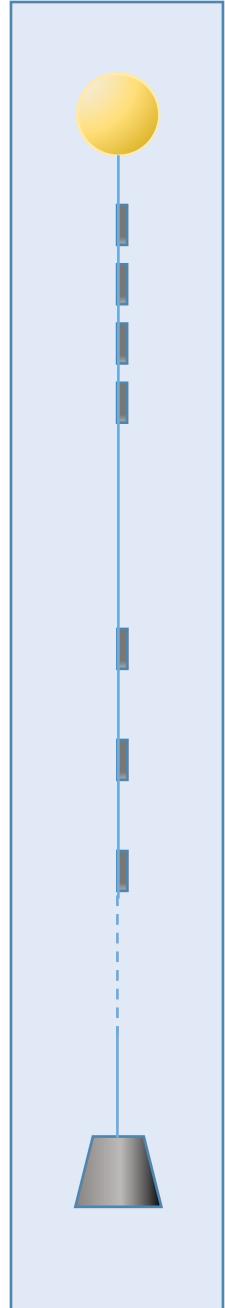
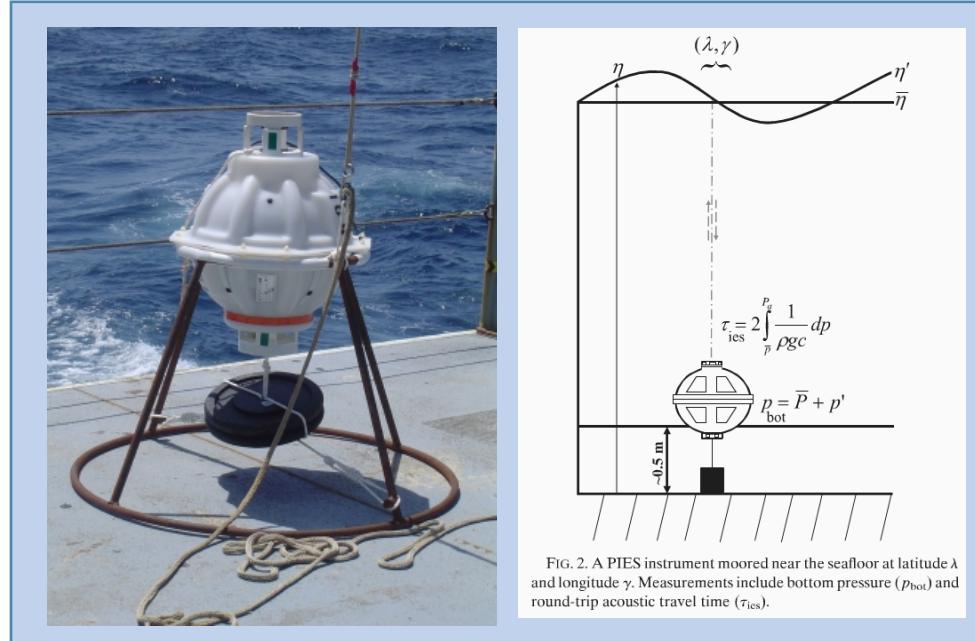
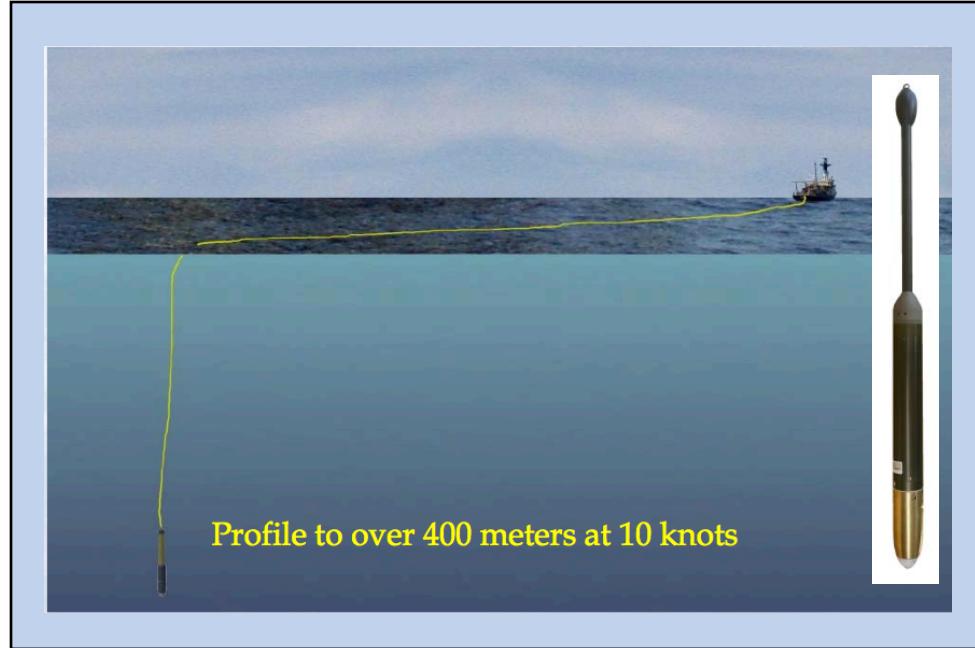
Combine PIES and UCTD

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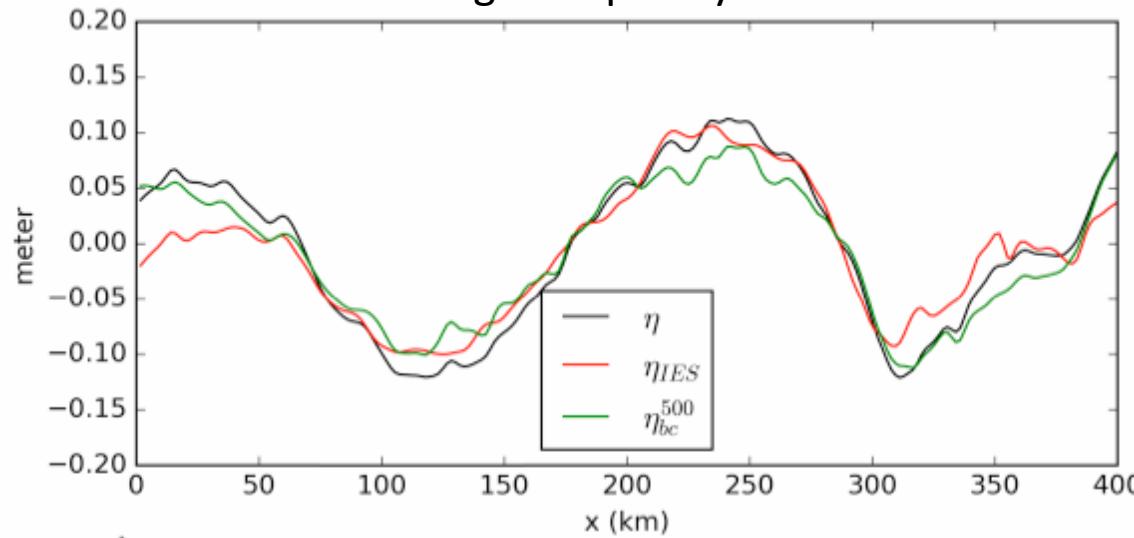


As a starting point,
we consider:

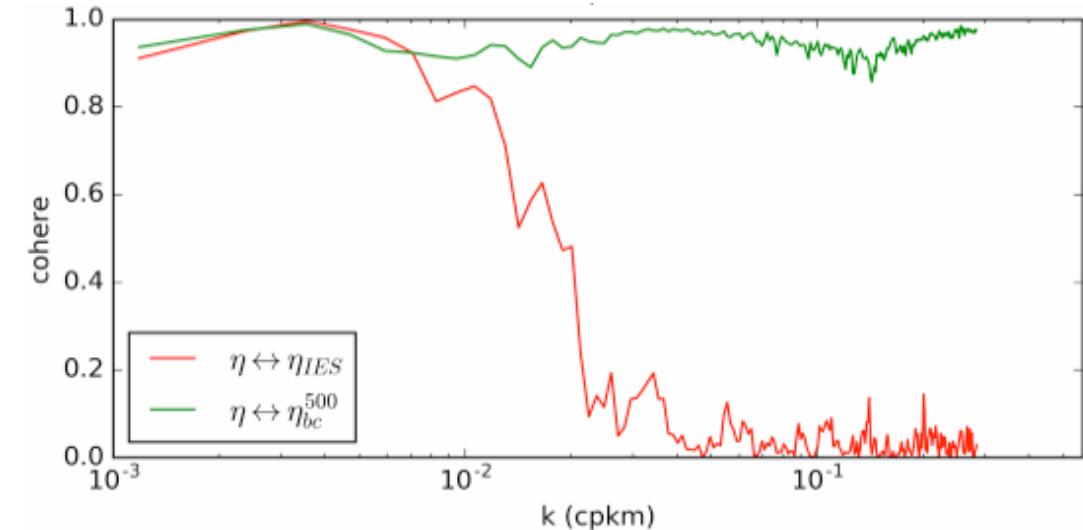
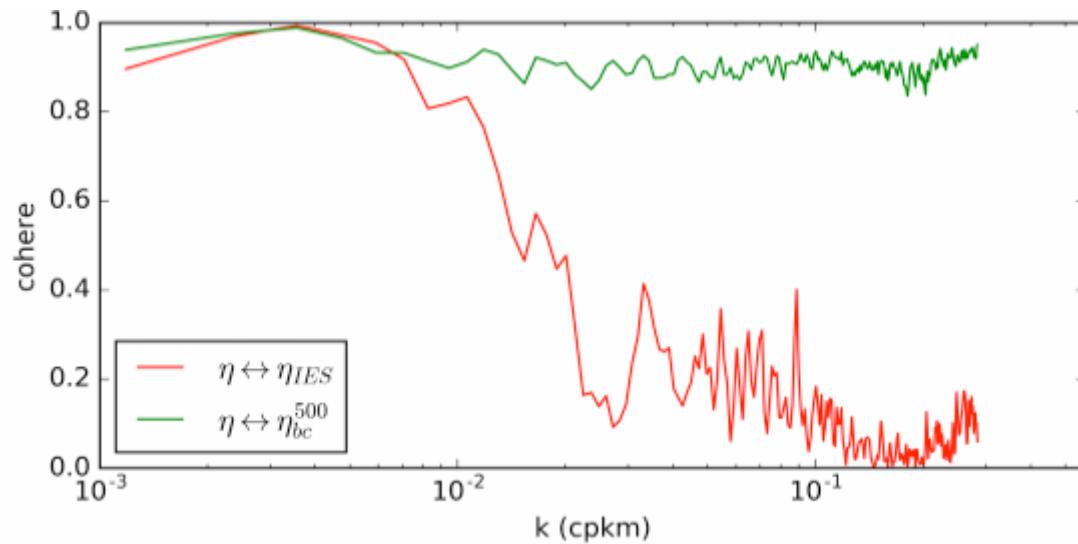
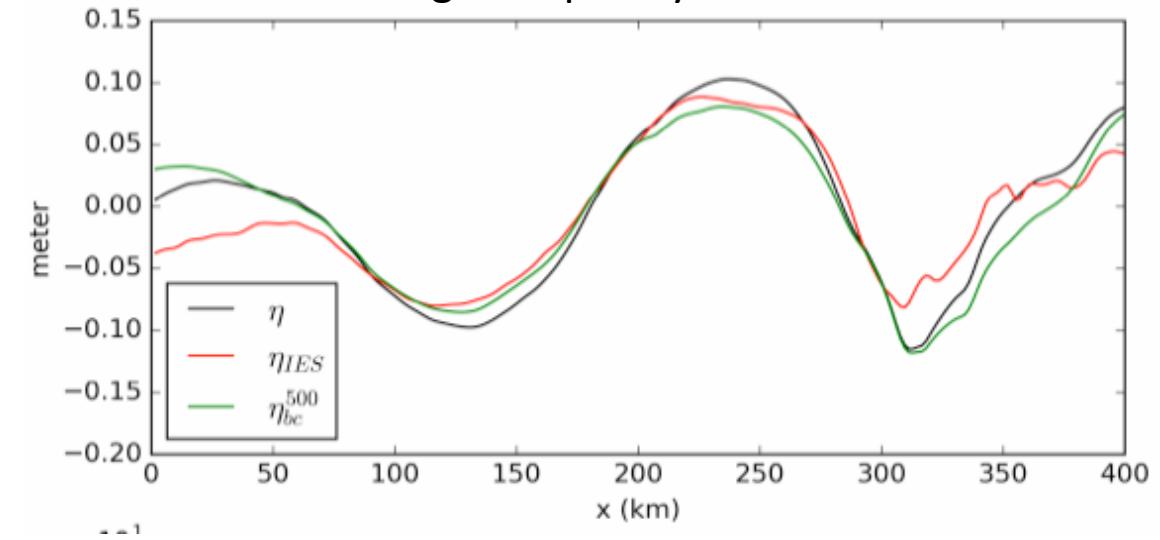
- UCTD
 - Fast upper ocean T/S sampling
 - Compact and portable
 - Needs ship time
 - logistically difficult
- PIES
 - High frequency sampling
 - Low cost
 - Long duration, easier for logistics
 - Single point measurement
- Mooring
 - High frequency sampling
 - Long duration, easier for logistics
 - Single point measurement
 - High cost



With high-frequency motions

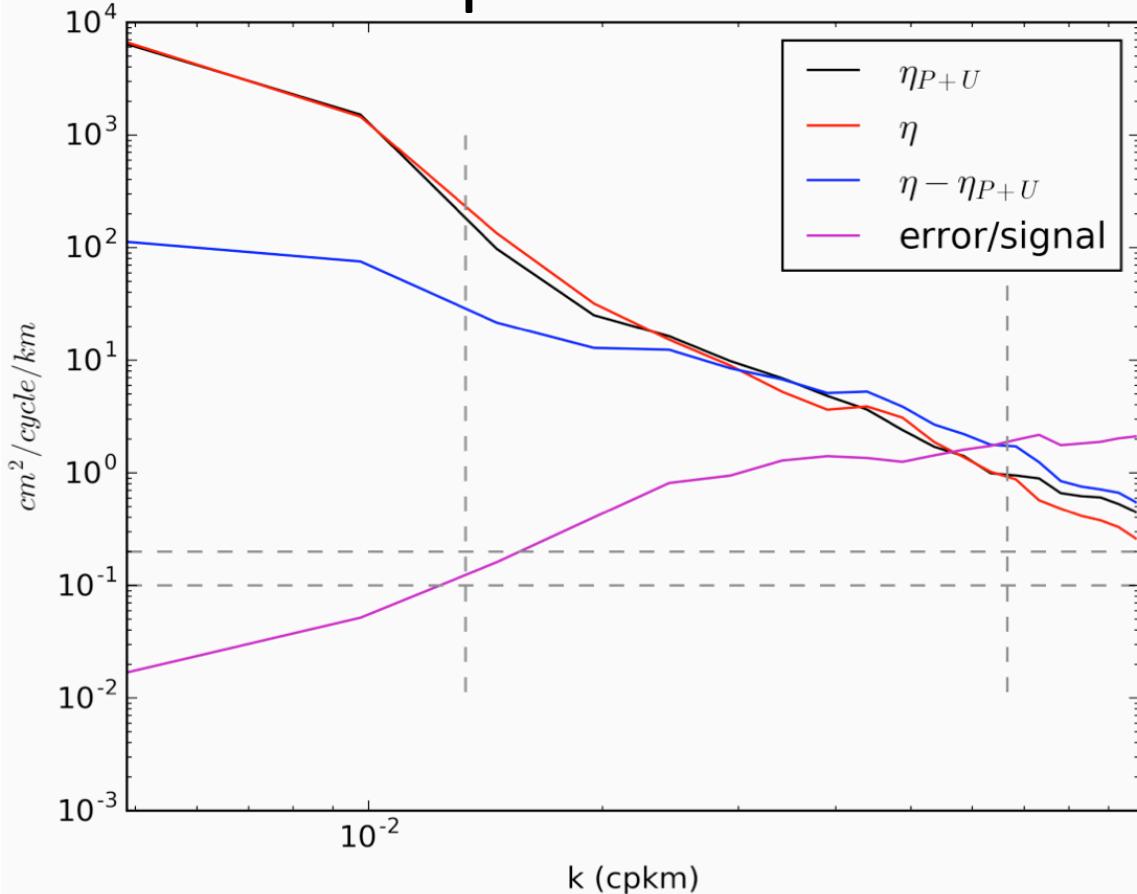


No high-frequency motions

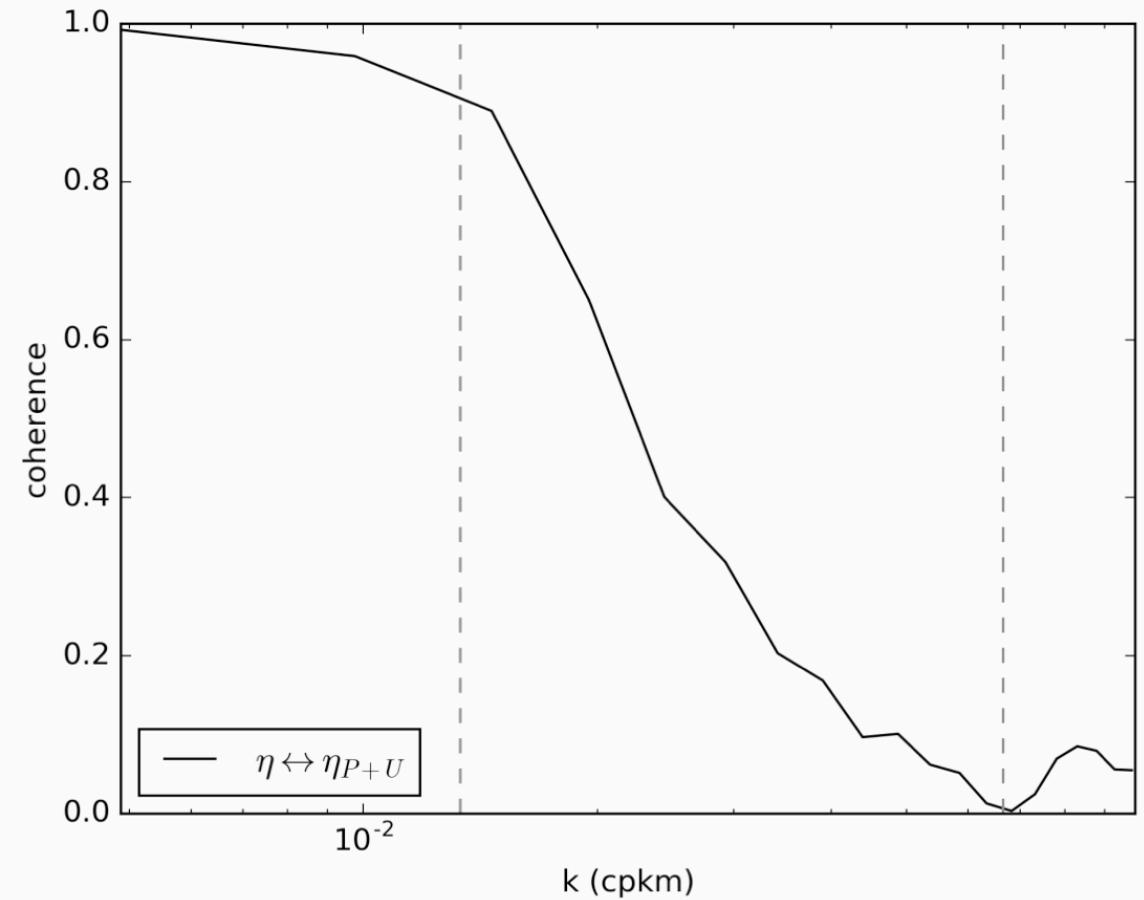


Influence of high frequency motions

Spectrum



Coherence



The low speed of the boat introduces aliasing.

The reconstruction is degraded over the submesoscale range after considering high frequency motions.

Large-scale signal in UCTD/PIES reconstruction is better due to the PIES contribution.

SWOT baseline requirement

- Based on wavenumber spectrum
- Need along-swath measurements
- A straight along-track line is the simplest configuration

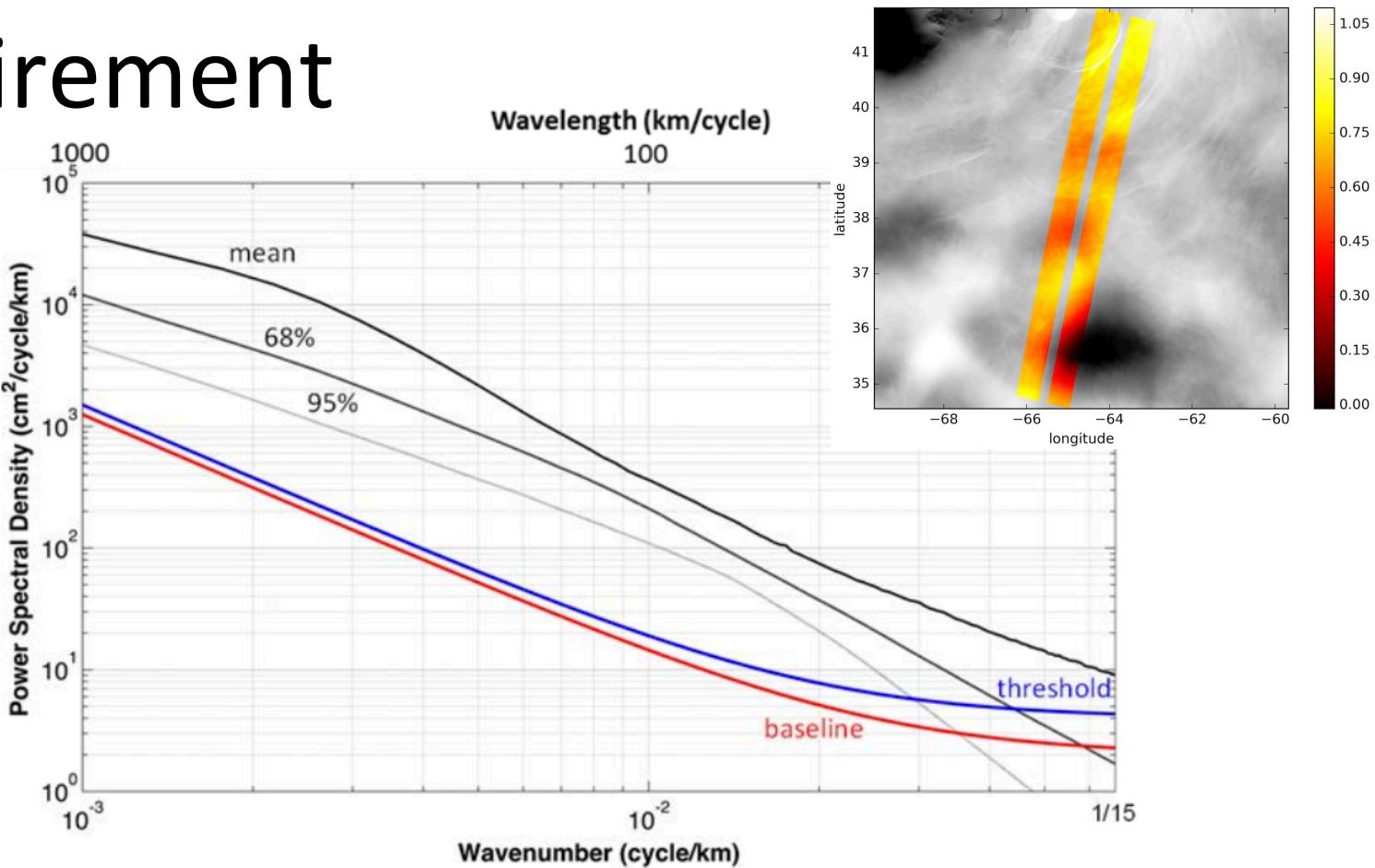
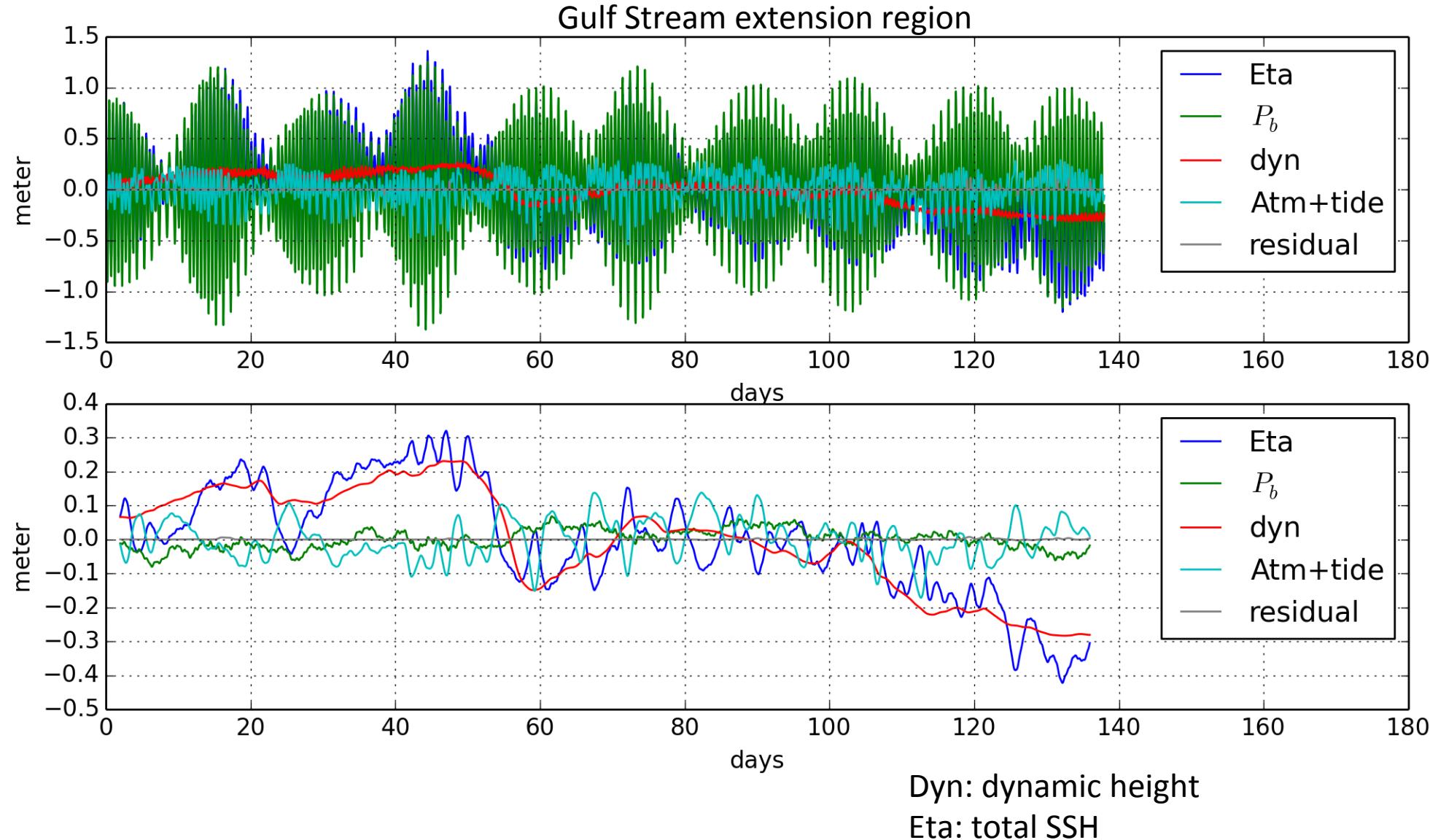


Figure 1: SSH baseline requirement spectrum (red curve) as a function of wavenumber. Blue curve is the threshold requirement. Shown, for reference is the global mean SSH spectrum estimated from the Jason-1 and Jason-2 observations (thick black line), the lower boundary of 68% of the spectral values (the upper gray dotted line), and the lower boundary of 95% of the spectral values (the lower gray dotted line). The intersections of the two dotted lines with the baseline spectrum at $\sim 15 \text{ km}$ (68%) and $\sim 30 \text{ km}$ (95%) determine the resolving capabilities of the SWOT measurement. The respective resolution for the threshold requirement is $\sim 25 \text{ km}$ (68%) and $\sim 35 \text{ km}$ (95%).

SSH budget is closed in ECCO2-ICE (llc4320)

We consider both total and low-frequency signals

Low frequency: Low-pass filtered with a 24-hour length Hanning window



Sea surface height in a hydrostatic model

$$\frac{d\bar{p}}{dz} = \bar{\rho}g; \quad \bar{\rho} = \rho_0 + \rho,$$

$$p(z) = p(0) + \int_{-z}^0 g\rho dz = g\rho_0\eta + g \int_{-z}^0 \rho(z') dz' + p_a,$$

$$\eta = \frac{p_b}{g\rho_0} + \int_{-H}^0 \frac{\rho(z')}{\rho_0} dz' + \frac{p_a}{\rho_0}.$$

Bottom pressure
Barotropic
component

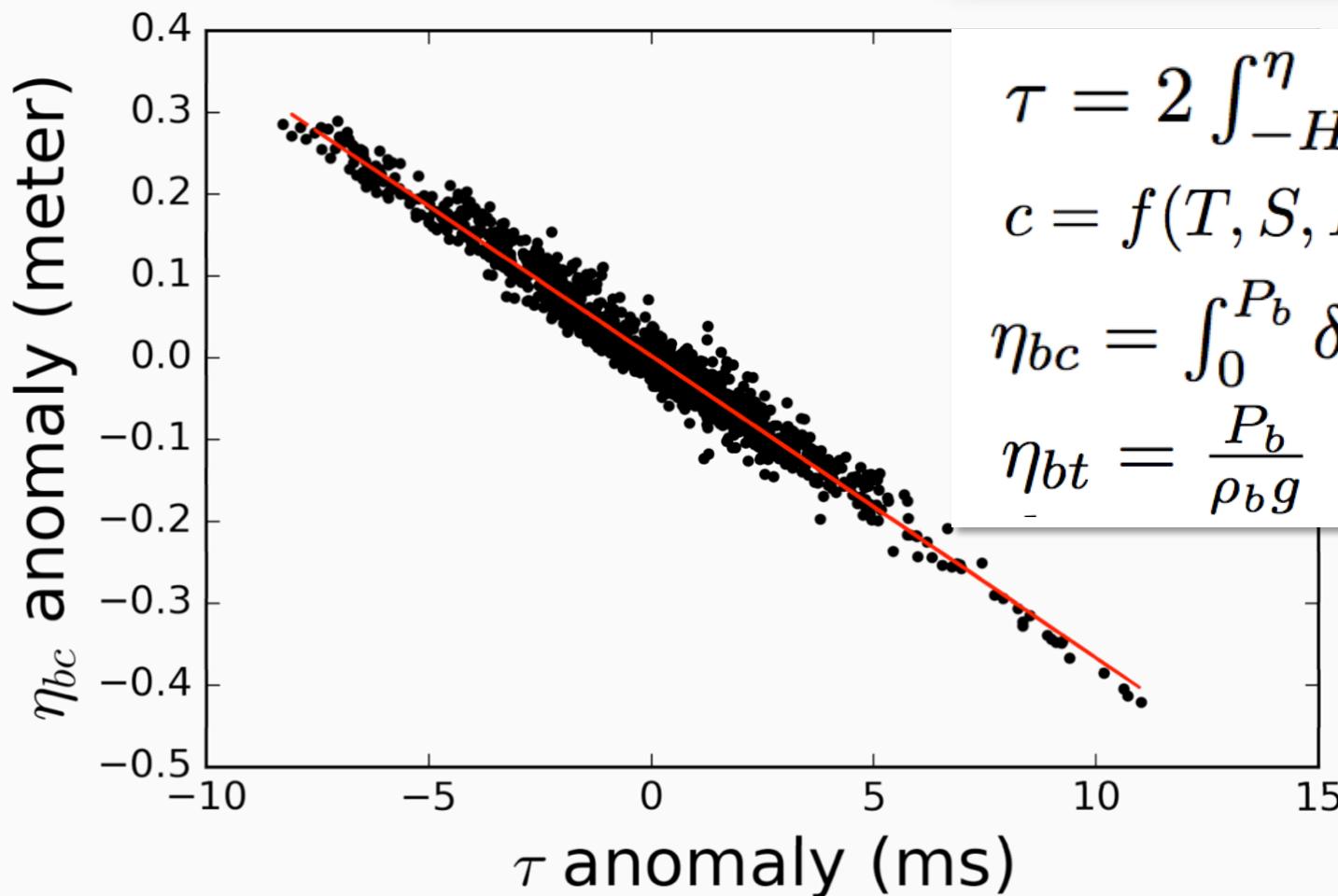
Steric height
Baroclinic
component

Atmosphere
loading

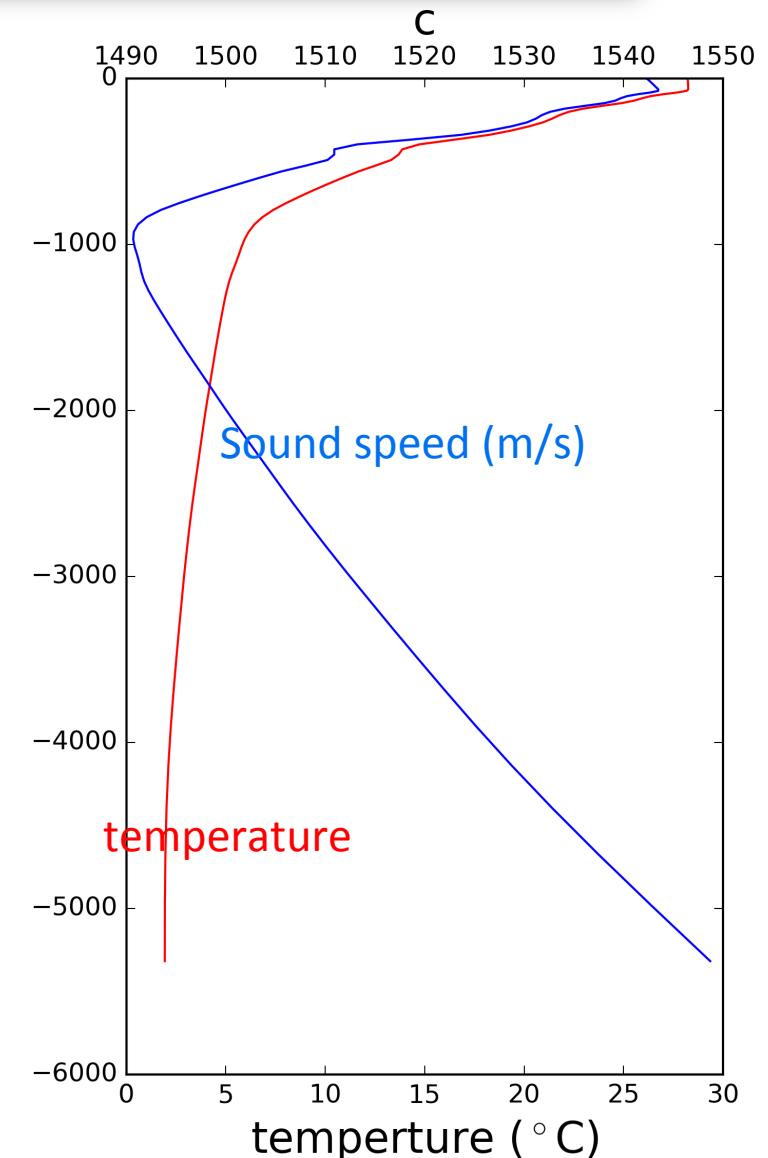
1. Barotropic component measured by bottom pressure
2. Steric component measured by density profile
3. Inverted Barometer effect by atmospheric pressure

Convert PIES to SSH

$$\eta_P = a_0 + a_1 \tau + a_2 \tau^2 + \eta_{bt}$$



$$\begin{aligned}\tau &= 2 \int_{-H}^{\eta} \frac{1}{c} dz \\ c &= f(T, S, P) \\ \eta_{bc} &= \int_0^{P_b} \delta dp \\ \eta_{bt} &= \frac{P_b}{\rho_b g}\end{aligned}$$



The high correlation between dynamic height and travel time is used to build a lookup curve based on local hydrological data.

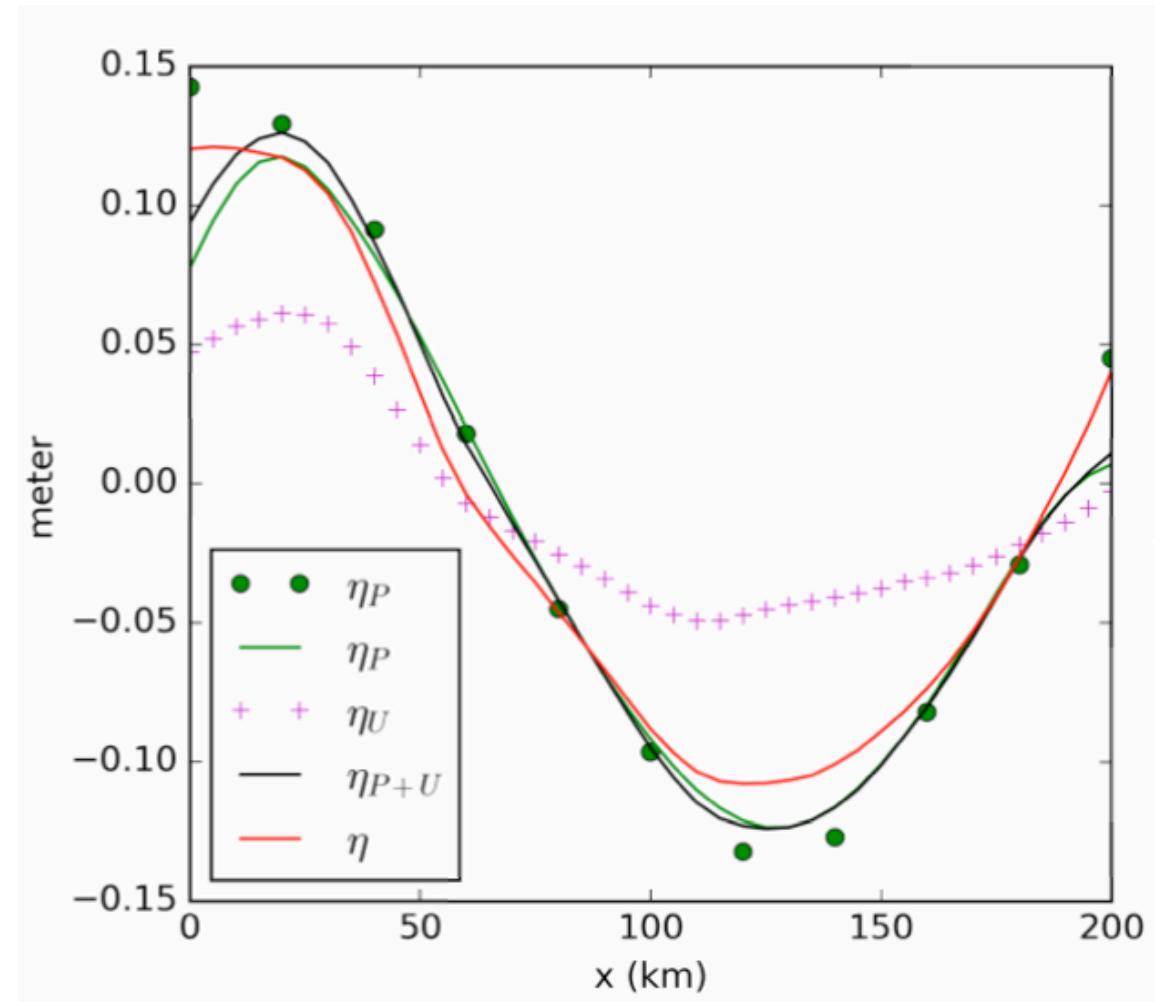
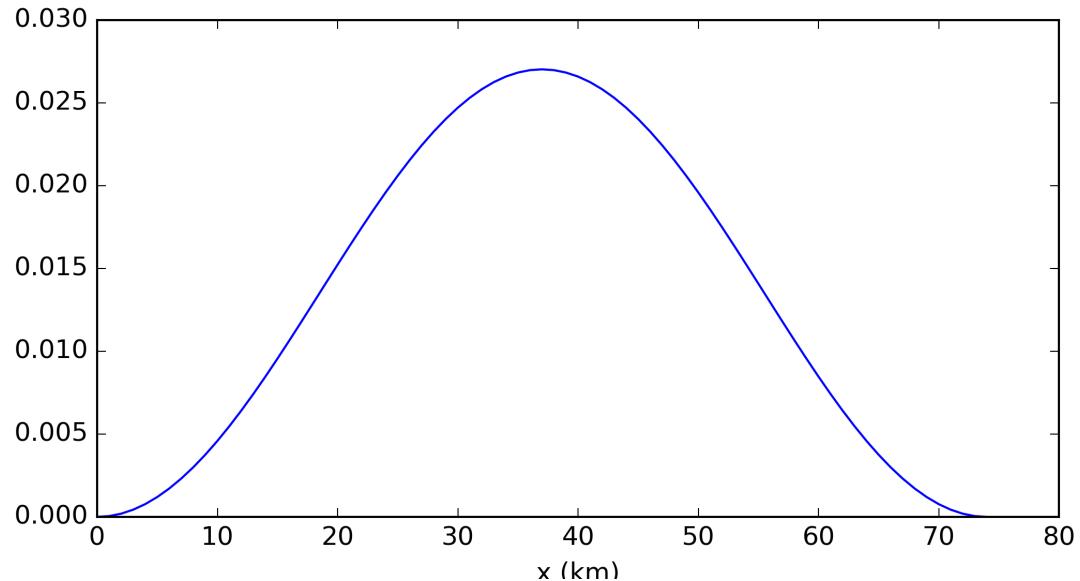
The lookup curve is used to convert travel time to dynamic height

PIES + UCTD

at low frequency

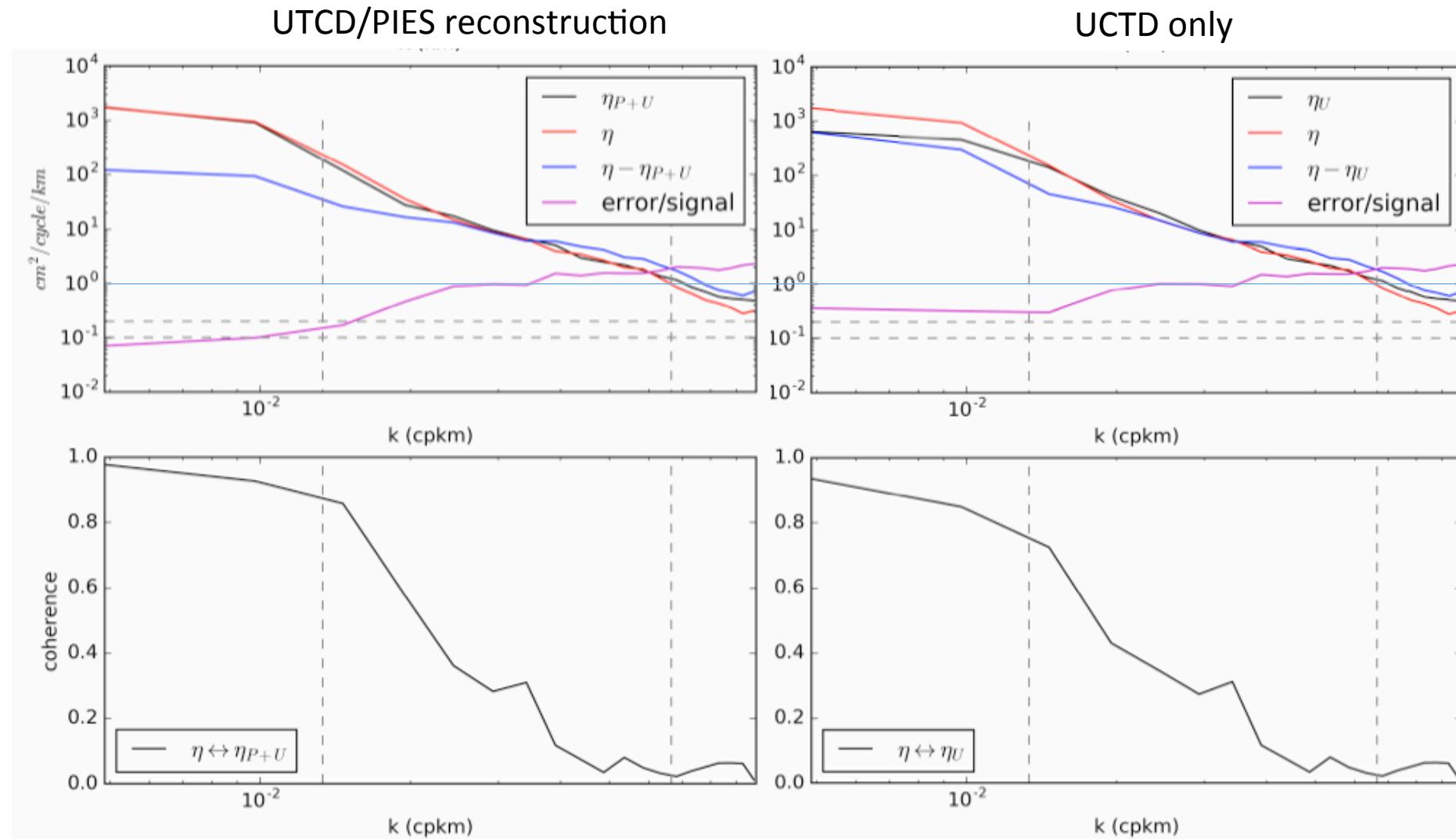
$$\eta(x) = (\eta_P * w)(x) + \eta_U(x) - (\eta_U * w)(x)$$

$$w(n) = 0.5 \left(1 - \cos \left(\frac{2\pi n}{N-1} \right) \right)$$



Use a 75km-wide Hanning filter to retrieve large-scale signal from PIES and small-scale signal from UCTDs.

Influence of high frequency motions



Large-scale signal in UCTD/PIES reconstruction is better due to the PIES contribution.